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The Institute Spokesman

NATIONAL LUBRICATING GREASE INSTITUTE

VOLUME VI • NUMBER 9 DECEMBER, 1942

Wishing You A Merry Christmas and A Victorious 1943

Flow Characteristics of Lubricating Greases

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(Continued from November issue)

The apparatus could be appreciably simplified by charging the grease directly to the pump and forcing it through a capillary attached to the pump outlet. This would eliminate the need for a hydraulic oil and a grease cylinder and piston assembly. Comparison of apparent viscosities determined by the two methods indicate that the shearing action of the pump on the grease appreciably reduces the apparent viscosity at rates of shear below 20,000 sec.$^{-1}$, as is indicated in Figure 5. Since the error involved at low rates of shear due to breakdown of the grease in the pump may actually amount to as much as 25% or more, the necessity of using the indirect method involving displacement of the grease from a cylinder by a hydraulic fluid is obvious.

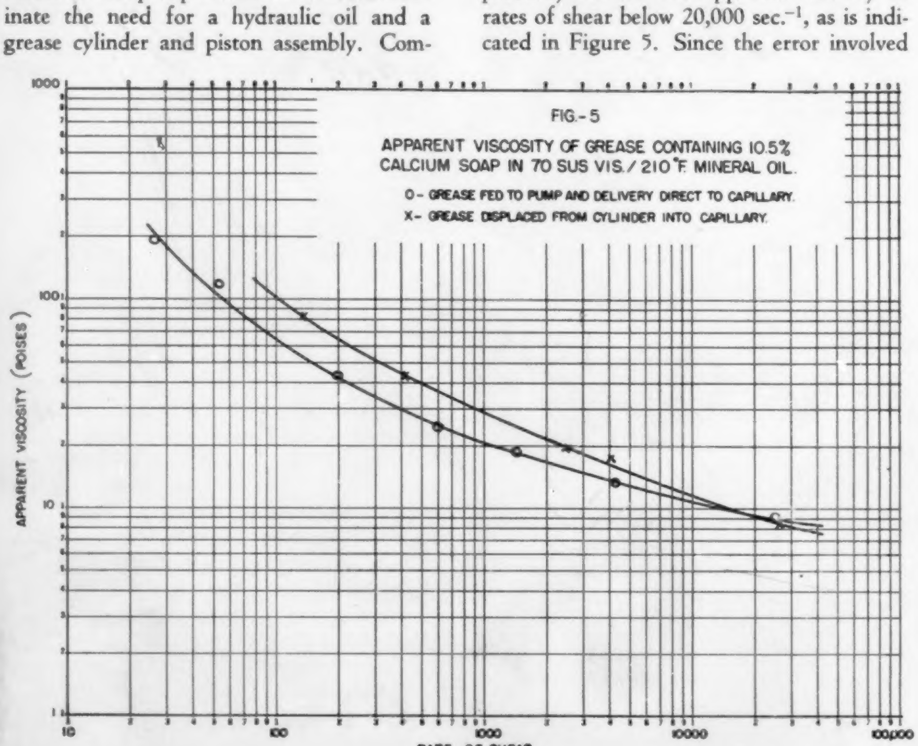

FIG.-5
APPARENT VISCOSITY OF GREASE CONTAINING 10.5% CALCIUM SOAP IN 70 SUS VIS./210°F MINERAL OIL.

Once the system has been calibrated for flow rates, it need be checked only at rare intervals, or when the pump has been accidently subjected to abnormal load. It is desirable, however, to have a revolution counter on the final drive gear of the pump for the purpose of checking pump speed, particularly if a variable speed transmission is employed to extend the range of the instrument.

The Capillaries

The capillary dimensions and materials used in their construction are listed in Table III. The stainless steel tubing was cold drawn to meet uniform diameter specifications by J. Bishop Company, Malvern, Pennsylvania. The details of the mounting for the steel tubing and the glass capillaries are shown in Figure 6. The capillary mounts were threaded with a ¼ inch pipe thread die to simplify their attachment to the grease cylinder. To insure against end effects and to facilitate accurate measurements of lengths, the tube ends were carefully ground to plane surfaces perpendicular to the tube axis.

TABLE III
Capillary Dimensions

Our No.	Effective Radius (Cm.)	Length (Cm.)	Type
1	0.1908	7.80	Stainless steel tubing
2	0.123	7.86	Stainless steel tubing
1A	0.0927	6.23	Drilled in ½" rod
4	0.0760	7.80	Stainless steel tubing
5	0.0615	4.13	Stainless steel tubing
5A	0.0503	6.56	Stainless steel tubing
6	0.0318	4.625	Glass
7	0.0231	4.03	Stainless steel tubing

The radius of each capillary was determined by viscometric means. Mineral oils, whose viscosity at a reference temperature (100°F) had been carefully determined using standardized Obbelohde tubes, were pumped through the capillary at a known, constant flow rate and the pressure observed. The flow rates were adjusted to give pressures of sufficient magnitude to be accurately read on a Bourdon gauge and the entire system was kept at the reference temperature by means of a liquid bath. The effective or viscometric radii were calculated using Poiseuille's equation with a reproducibility within ± 0.5%. Calculations showed that for the flow rates employed with the capillaries, the kinetic energy correction was insignificant.

PRESSURE MEASUREMENT

The amount of pressure which can be developed ranges from 0 to 2 lbs./sq. in. for the most fluid grease and the largest capillary up to 1500 lbs./sq. in. for the heavier greases and the smaller capillaries. Pressures above 10 p.s.i. may most conveniently be measured by a series of Bourdon gauges of ranges which overlap sufficiently so that they may always be used in the middle one-third of their scale, where they are most accurate. These gauges should be checked frequently, either on a deadweight hydraulic tester or against standard test gauges. When pressures less than 10 p.s.i. are to be measured a mercury manometer attached directly to the oil line provides satisfactory results.

For studies at 77°F or higher, the measurement of pressure developed in the hydraulic fluid is satisfactory since experiments show that the amount of friction generated by the piston displacing the grease from the cylinder at the flow rates used is negligible. Any known method of measuring the pressures developed within the grease would make the instrument too complex for routine use, although a pressure block, such as employed by Arveson, would be desirable for very accurate work, particularly at low temperatures.

When the grease and hydraulic oil are cooled to temperatures around −40°F or below, the friction arising from the passage of the piston over a film of the cold grease on the cylinder wall is appreciable. Experiments show that this friction may involve an error as high as 5-10% at low pressures, and therefore the data at low rates of shear need be corrected if better accuracy is desired. At high rates of shear where high pressures are involved this error probably would not be significant. Observing the pressure required to move the piston and displace grease from the open end of the cylinder at the test temperature, without the capillary and thermocouple mounting cap gives the necessary correction factor.

The time necessary for equilibrium pressure to be reached with the recommended flow rates is less than 10 minutes and the final reading is taken when there is no measurable increase in pressure for three readings at 30-second intervals. This pressure value should be corrected by addition of the gravity head when testing fluid greases containing low viscosity mineral oils.

TEMPERATURE CONTROL AND OPERATION

The reference temperature employed for the grease tests is 77°F (25°C) and preliminary studies on the grease viscosimeter were greatly facilitated by the use of a constant temperature room continuously controlled to within one degree of this temperature. The samples were stored in this room for several hours prior to the determination in order to assure uniform temperatures during the run.

The grease sample is loaded into the cylinder (cf. Figures 2 and 4) by means of vacuum suction. The piston was held in a position flush with the lower edge of the cylinder, which in turn was immersed in the grease sample. Vacuum was applied through the valve on the upper arm of the unit (cf. Figure 2) and controlled by careful use of the valve. The grease slowly follows the piston up into the cylinder and a smooth "fill" is obtained. This insures the absence of air bubbles or pockets in the test sample, provided the grease has been previously freed of air bubbles. The vacuum is shut off when the cylinder is filled and the valve is allowed to remain open. The thermocouple mounting and capillary are then placed in the ¼ inch pipe threaded holes in the cylinder cap and tightened. The cylinder cap carrying the capillary is then screwed into the cylinder and the pump is started and allowed to run until a uniform stream of the hydraulic oil passes the valve, indicating that all air bubbles have been removed from the oil line. The valve is

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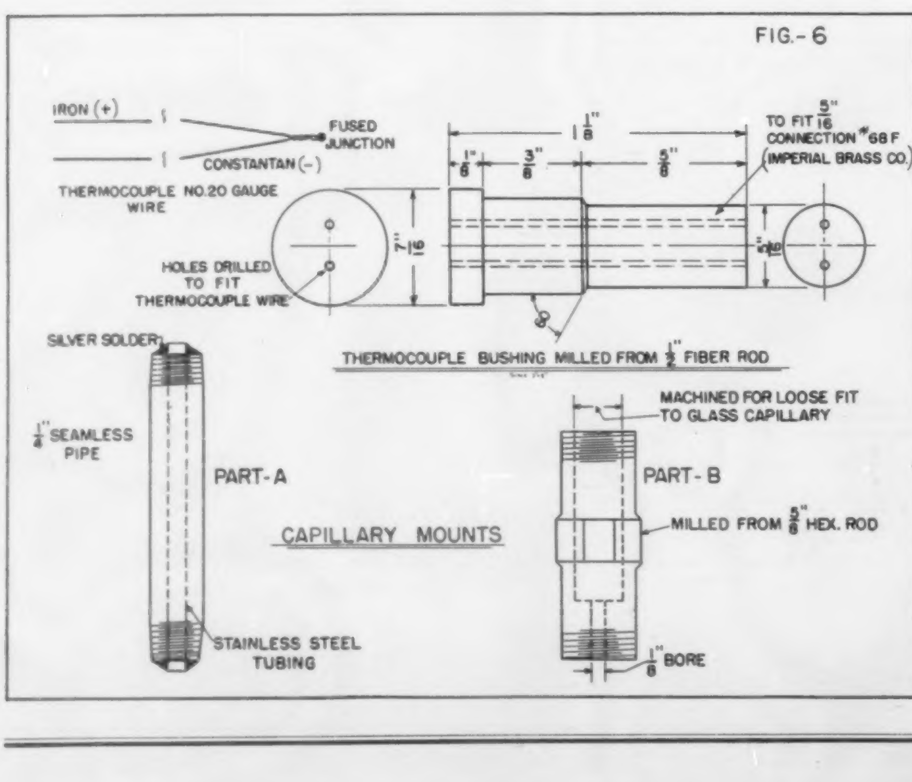

The INSTITUTE SPOKESMAN

Published monthly by

THE NATIONAL LUBRICATING GREASE INSTITUTE

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Arnon N. Benson, Joins Chek-Chart

Arnon N. Benson has joined the staff of The Chek-Chart Corporation, Chicago, as Business Manager as of Nov. 16.

Benson has had a long career in the automotive industry, particularly in association work, having been General Manager of the National Automobile Dealers Association during the very critical years from 1936 to 1939 and having previously developed and operated the Minnesota Automobile Dealers Association over a period of some 14 years. More recently he published the Automobile Dealers Market Record, a monthly used-car valuation service.

Benson's work and experience in his association activities covered the development and promotion of improved merchandising and operating procedures, public relations, collection and dissemination of information and statistics, employee training systems, editing the association publications, staging automobile shows, handling of industry legislative matters and cooperating with various other associations for the production of a unified national association program.

Benson brings to The Chek-Chart Corporation a large fund of knowledge and experience which will prove of the greatest value in the continued improvement and extension of CHEK-CHART service to its clients in the automotive and oil industries and to the U. S. Army in the preparation of lubrication guides, bulletins and lubrication manuals.

Flow Characteristics of Lubricating Greases

(Continued from Page 2)

closed and a preliminary trial with a wide range pressure gauge gives the approximate pressure, thus indicating the proper gauge to use for maximum accuracy. The grease is forced through the given capillary until equilibrium pressure is attained, and it is this final pressure which is used in Poiseuille's equation for the calculation of apparent viscosities. The pump is then stopped, and the pressure released by venting the hydraulic oil through the upper valve. The capillary is changed and the process repeated until the desired range of shear rates is covered.

Naturally for temperatures other than 77°F or when a constant temperature room is not available, a bath must be used. Such a bath, designed to operate over a range from −40°F to +300°F, is illustrated in Figure 7. Several cylinders with complete attachments up to the ¼" pipe union (Figure 2) were made up and used for a series of tests. Thus, while one grease sample was being run, others were stored in a bath or other suitable container held at the desired test temperature.

For measurement at very low temperatures it is possible to immerse the entire cylinder in a horizontal position in a bath of dry ice-alcohol and so forth. In addition to the necessary change in pipe connections to the pump, a reservoir or sump to catch the extruded grease should be attached to the efflux end of the capillary. This sump must be vented to the atmosphere to avoid building up pressure in the receiver. The cylinder to be employed for a test is placed in position in the bath, joined to the hydraulic system at the union and after thermal equilibrium is established the run is completed as described above. Any changes in grease temperature are manifested not only by the thermocouple responses but by deviations in pressure as well. The temperature of the grease which is measured adjacent to the capillary inlet should be controlled to within one degree Fahrenheit in order to insure reasonable accuracy. In runs using the constant temperature room, a reproducibility of 3% was obtained on the calculated apparent viscosity.

The heat generated in the capillary is also a possible source of error. The work done when the grease is sheared during passage through the capillary may cause an appreciable rise in the temperature, particularly at high rates of shear. Since the shear is greatest near the axis of the stream flowing through the capillary, it is here where temperature effects should be the largest. In the viscosimeter, however, the observed pressure is a measure of the summation of all resistances throughout the stream, and, therefore, it is logical to assume that the average temperature of the main body of the grease during shear is the important factor in judging heat effects. Corrections based on the arithmetical average temperature should, therefore, be sufficiently reliable. However, when working at 77°F with the soft and medium grades of lubricating

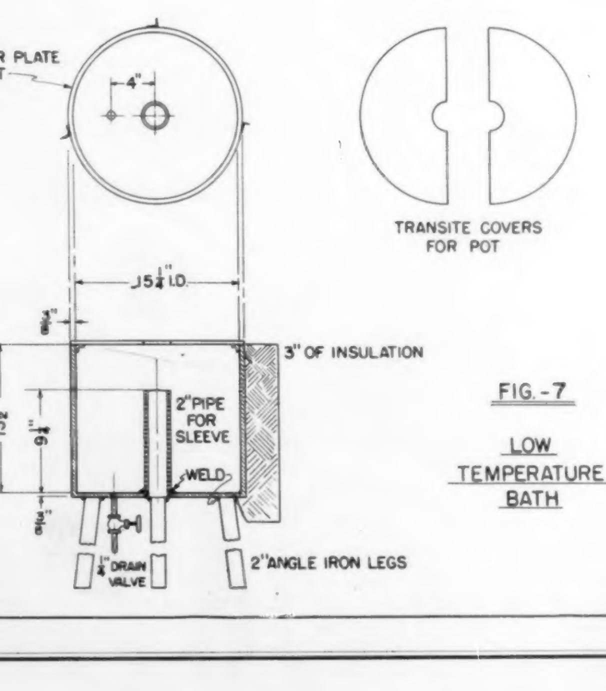


FIG.-7

LOW TEMPERATURE BATH

greases containing oil of less than 1000 SUS/100°F. viscosity, which includes the majority of the products in general use, the temperature of the efflux grease, measured with a four-junction thermocouple of low heat capacity, showed less than 1°F increase at rates of shear up to 10,000 sec.$^{-1}$. Except, therefore, for heavy greases at very high delivery pressures, correction for heat effects in the capillary may be disregarded.

Significance of Viscosity Measurements

The apparent viscosity of a grease at any given rate of shear is dependent mainly on the viscosity of the mineral oil, the amount and type of soap and the temperature. Less important factors which become evident only at the lower rates of shear are differences in the amount of preworking of grease, solidification of the mineral oil content at temperatures below its pour point, the water content of lime soap grease, etc.

Arveson made a detailed study of the effect of soap content on grease viscosities, and representative data are presented in Figure 8. He showed that the viscosity of the grease decreases with increasing shear rates and at high rates approaches that of the mineral oil base. This drop in viscosity of the grease at high rates of shear accounts for its ability to lubricate a high speed bearing without excessive drag and the development of high frictional temperatures. The very high viscosity at low rates of shear, on the other hand, is indicative of its ability to remain in a bearing without excessive leakage and consumption. The grease, however, always maintains a viscosity above that of the base oil even at shearing rates about 100,000 sec.$^{-1}$, and the difference is proportional to the soap content. From this, Arveson estimated a so-called soap factor, accounting for the portion of viscosity due to the thickening action of the soap. The soap factor, of course, varies for different types of soaps. This is illustrated in Figure 9, which compares the apparent viscosity versus rate of shear curves of three conventional type chassis greases made up to the same approximate unworked penetration from different soaps, but the same base oil of 70 SUS vis 210°F, as follows:

Cf; Arveson, M.H., Ind. Eng. Chem., 24, 74 (1932)

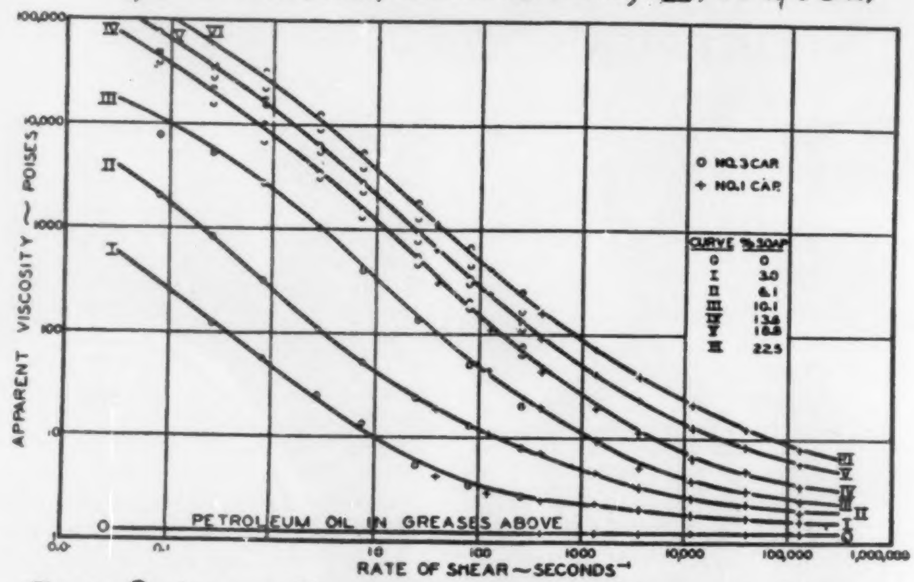
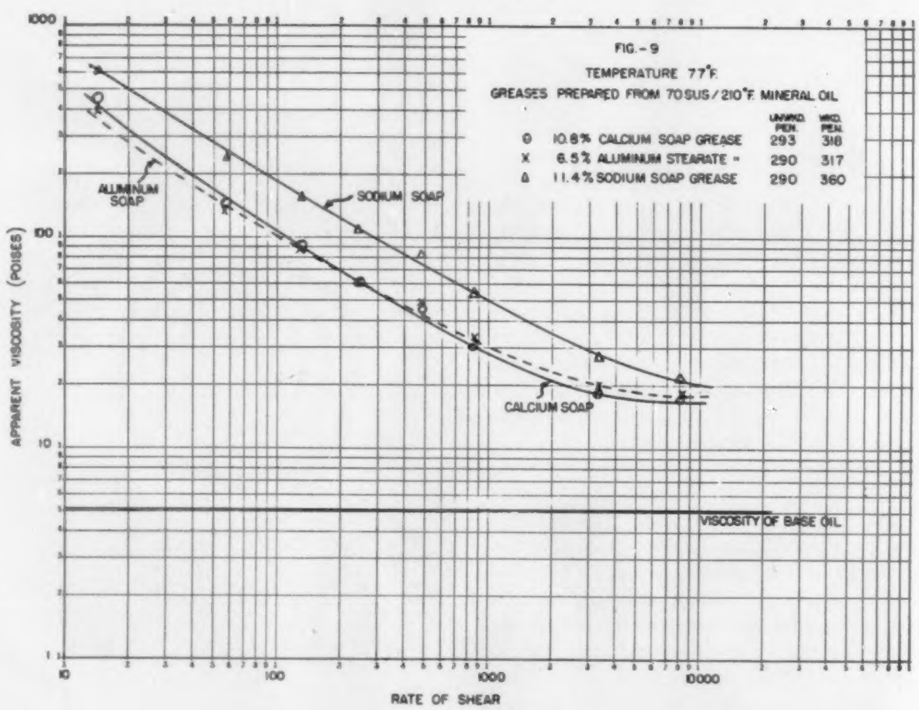


FIGURE 8 APPARENT VISCOSITY–RATE OF SHEAR DIAGRAM OF SERIES OF CUP GREASES



	ASTM Penetrations at 77°F Unworked	Worked
6.5% Aluminum Stearate	290	318
10.8% Calcium Soap	293	317
11.4% Sodium Soap	290	360

The aluminum and lime soap greases have the same worked penetrations and similar apparent viscosities. The difference of some 40% in the soap content of these two products is illustrative of the greater thickening power of the aluminum soap. The sodium soap is the least effective thickener and approximately double the amount of soap used in the aluminum grease is necessary to secure a 290 unworked penetration. The soda grease has the highest apparent viscosity, but its worked penetration is some 40 points greater than those of the aluminum and calcium products.

The degree of thickening or increase in apparent viscosity due to a given amount of soap can, of course, vary with the amount and severity of the preworking a grease has been subjected to. This is illustrated in Figure 10, depicting the apparent viscosities of a lime base grease containing 10.2% soap dispersed into a 49.6 SUS/210°F, −10°F pour point oil, before and after passage through a colloid mill. Although the penetration at 77°F remained the same, the apparent viscosities are quite different over the temperature range −25 to

75°F, indicating that some breakdown of the soap structure and loss of thickening power, occurred during the passage of the grease through the colloid mill.

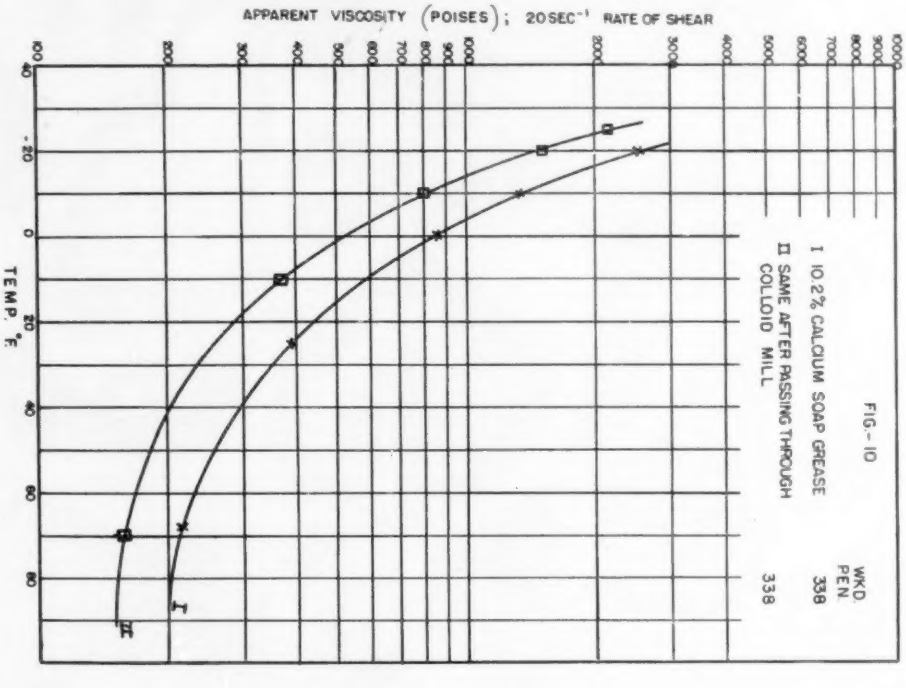
CORRELATION OF VISCOSITY VALUES AND PERFORMANCE

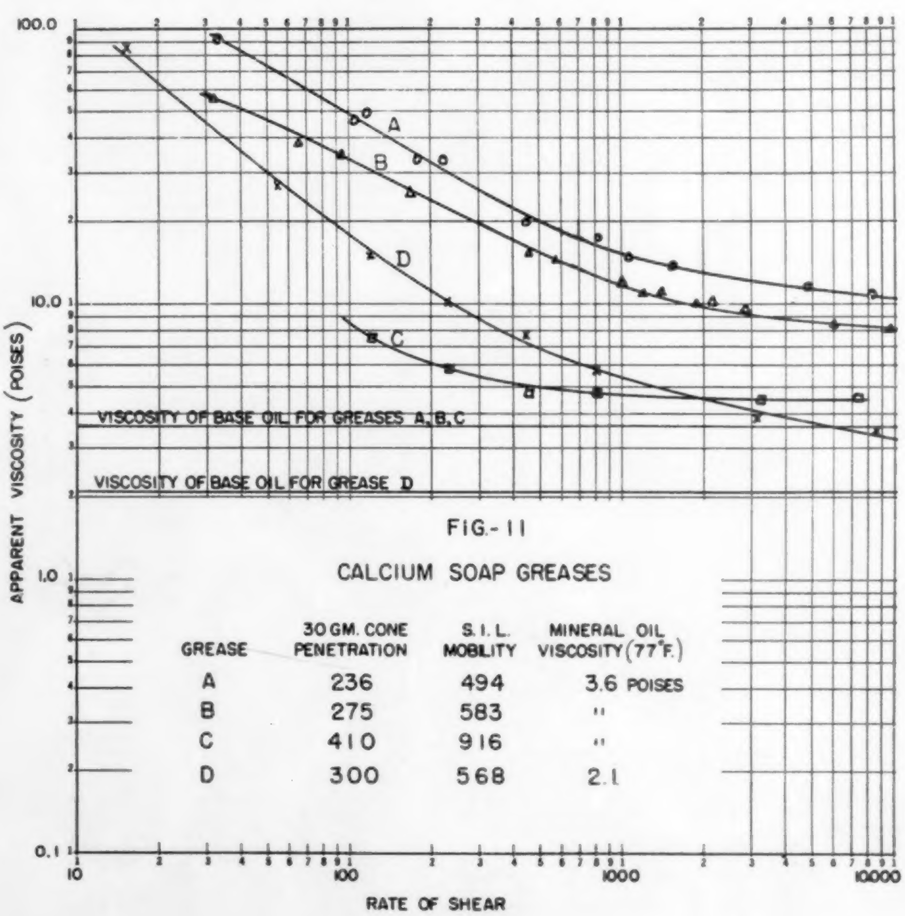
The possibility of estimating leakage or consumption characteristics of greases from their apparent viscosities at low rates of shear, plus the indication of relative lubricating ability at the higher shear rates is of particular interest in the case of semi-fluid greases. The performance and thus the application of these products, which contain only a few per cent of soap to minimize leakage, are determined primarily by the viscosity of the mineral oil base. Apparent viscosities over a range of shear rates permit distinctions to be drawn between the effect of the soap and the oil, and show the two in their correct relationship. The usual consistency determinations with 30 or 50 gram cone load penetrations or plunger instruments, such as the Gardner or S.I.L. Mobilometers, on the other hand, measure the combined effect of the two variables. Further, they tend to accentuate the effect of soap content and thus may be misleading.

This is illustrated in Figure 11, giving the apparent viscosity rate of shear curves for several semi-fluid lime soap greases. Grease A, B, and C contain the same mineral oil and show the effect of decreasing soap content. The apparent viscosities of A and B are quite high at rates of shear below 1000 sec.$^{-1}$, while that of C, which contains the smallest amount of soap is not greatly different from that of the mineral oil base. At higher rates of shear, however, the differences in the viscosities of the three products are appreciably smaller, indicating similar lubricating characteristics. Comparison of the curves for Greases B and D, which contain different oils, but substantially the same amount of soap indicates the marked effect of oil viscosity on the flow characteristics of semi-fluid greases.

Similar apparent viscosity-rate of shear curves for semi-fluid soda base and aluminum base lubricants containing oils of different viscosities are shown in Figures 12 and 13, respectively. These curves show the difference in flow characteristics which may be expected, and they rate the products according to their relative service performance. For the soda base greases the consistency values are in the same order as the apparent viscosities. In the case of the semi-fluid aluminum base lubricants, however, this is not necessarily true, as indicated in Figure 13. Here the winter grade, tractor lubricant has the higher consistency and appears heavier than the summer grade.

Another application of apparent viscosity data is the comparison or prediction of the dispensing characteristics of greases. In comparative tests, for example, at 0°F, dispensing two semi-fluid greases from an Alemite 6521 Caterpillar Volume Gun, one containing a 50 SUS/210°F. viscosity mineral oil could be pumped into the bearings while a similar product containing 59 SUS/210°F mineral oil could not. The apparent





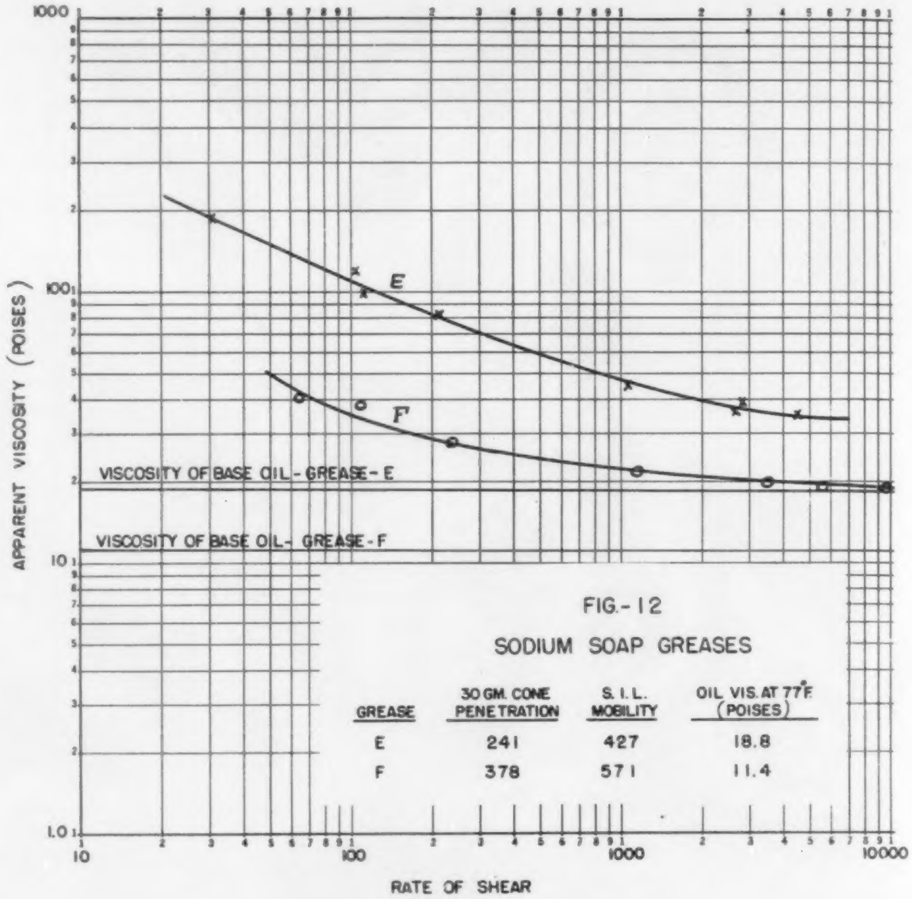
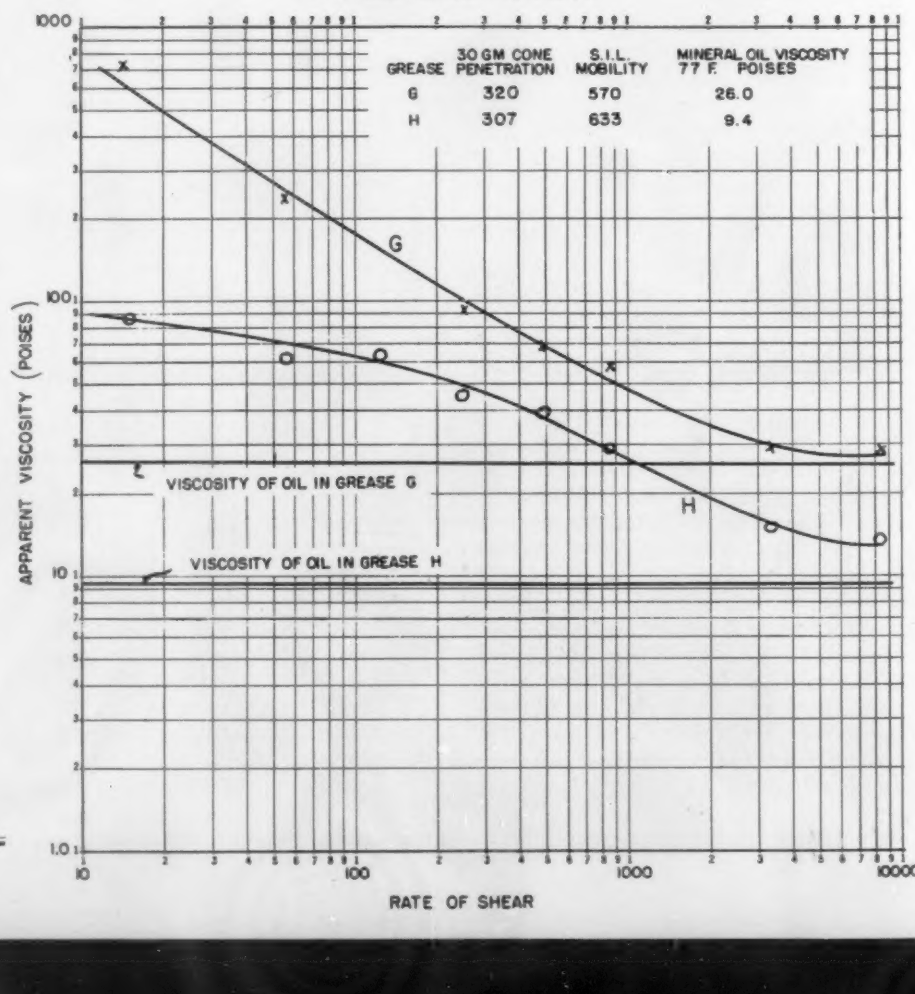


FIG.-12
SODIUM SOAP GREASES

FIG.-13
ALUMINUM SOAP GREASES



viscosity values of the products at 77°F were substantially the same, as is indicated in Figure 14. Measurements, however, at 0°F show approximately a two-fold difference in apparent viscosity at 1000 sec.$^{-1}$ rate of shear, and these data could be readily used to specify a maximum acceptable viscosity to insure satisfactory dispensability at low temperatures. The consistency data on the two greases, including determinations at 0°F, which are listed below do not show differences large enough to justify a conclusion that one product could be dispended at 0°F, while the other could not.

Correlation of the viscosity values with the performance of greases involves comparison of the service results with the apparent viscosity or the mobility at several rates of shear in order to determine at what flow rates comparison can be made. In other words, the effective rate of shear encountered in the application under consideration is determined by trial and error comparisons with the viscosity or mobility values. This is illustrated by work done at the Imperial Oil Limited laboratories on consumption characteristics of chassis lubricants. The laboratory test apparatus consisted of a Chevrolet rear spring supported by two plain shackles and actuated by a cam so

FIGURE 15

constructed to give both lateral and vertical motion (see Figure 15). The shackles were charged with a known quantity of grease, the cam operated for a given time and the amount of grease which leaked out of the bearing was accurately determined. The consumption was expressed as the percentage of the total grease charge lost during the operation, and could be reproduced within a few per cent. In a series of 12 greases the most efficient chassis lubricant, which gave approximately 1500 miles satisfactory lubrication on a 1937 Buick car equipped with pin and bushing shackles, showed a loss of 11% in the laboratory test. The poorest grease gave a consumption of 27%, and less than 300 miles' operation before development of shackle squeaks with the 1937 Buick.

(*To be continued*)

Grease	30 Gm. Cone at 77°F	150 Gm. Cone at 0°F	S.I.L. Mobility at 77°F	Base Oil Vis. at 210°F	Base Oil Pour Point °F	Dispensable at 0°F
I	300	372	568	59	0	No
J	335	382	600	50	−10	Yes